Calibration of Historical and Future AVHRR and GOES Visible and Near-Infrared Sensors and the Development of a Consistent Long-Term Cloud and Clear-Sky Radiation Property Dataset

Patrick Minnis, Kris Bedka, Dave Doelling, Qing Trepte
Rabindra Palikonda, Ben Scarino, Daniel Morstad
Climate Sciences Branch
NASA Langley Research Center
757-864-5671; p.minnis@nasa.gov
Jack Xiong, NASA GSFC   Fred Wu, NOAA NESDIS

Overview

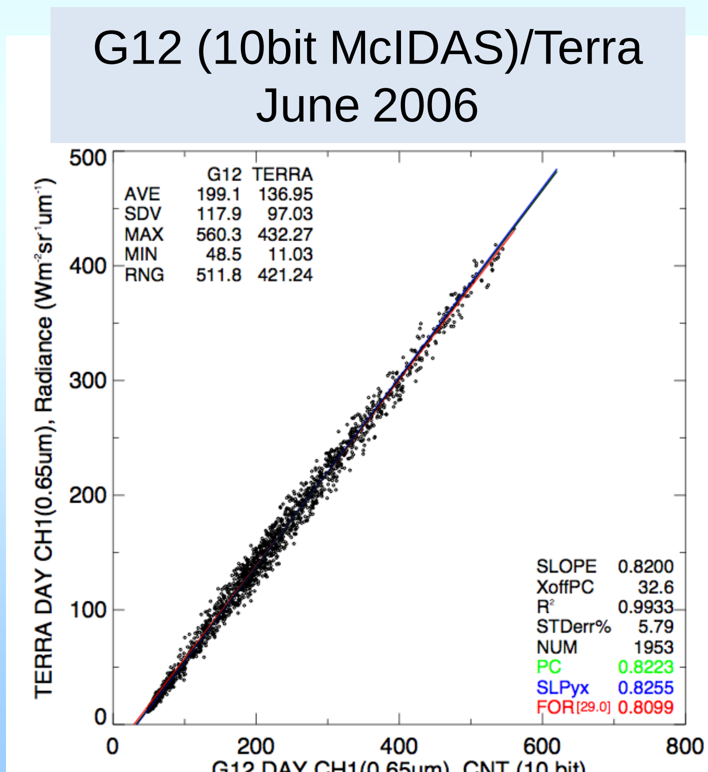
- Goals
  - Calibrate AVHRR 0.64, 0.87, and 1.6-µm channels
  - Calibrate GOES & SMS imager 0.65-µm channels
  - Generate CERES-like cloud climatology from AVHRR record
- Source Data
  - AVHRR 1, 2, & 3: 1978 – present
  - SMS-1 & 2; GOES-1 thru present
  - SCHIAMACHY spectral data (2004-2009)
- Deliverables
  - Calibrated 0.63 & 0.86-µm radiances (calibration coefficients)
  - Cloud temperature, height, optical depth, effective particle size, water path, phase; surface skin temperature, spectral albedo
- ECVs addressed: cloud properties, radiation budget
- Current/expected user communities: GEWEX, GCM community, energy, aviation

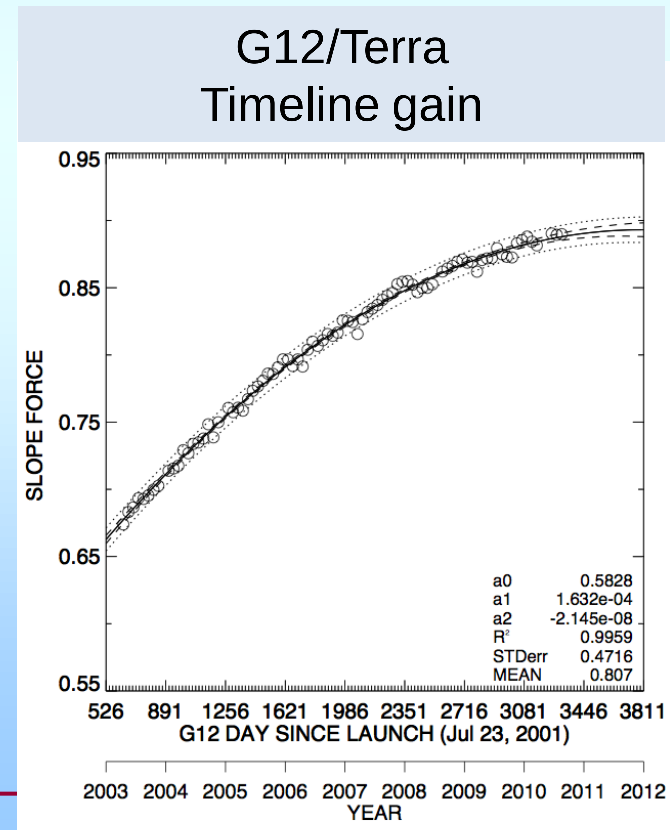
Solar Channel Calibration Approach

- Use Aqua-MODIS as the absolute calibration reference
  - Aqua more stable
  - Better characterized
  - Not based on the absolute calibration of Aqua of Terra
- Develop spectral corrections for each satellite using SCIAMACHY
  - Use ratios for cross-calibration (Doelling et al., GSRL, 2011)
  - Perform AVHRR DCC and desert calibration
  - NOAA orbits degrade over time, Accuracy limited to SZA < 55°
  - Develop DCC BRDF corrections using VIRS
- Use Geostationary satellites as calibration references
  - Have a set image scheduling, always have data w/ SZA < 55°
- Calibrate each GEO independently
  - 2000-2008 GEOs use MODIS/GEO ray-matching, DCC and deserts
  - 1985-1999 GEOs are based on DCC and desert only, tied to 2000+
- Transfer all simultaneous GEO calibrations to a given AVHRR
  - All GEO calibrations should yield same AVHRR sensor degradation
  - AVHHR DCC-> trend mean of GEO cross-calibrations-> gain
- Compare with ISCCP & other published calibration coefficients

Ray-matching to reference sensor

- Ray-match coincident GEO counts, radiances and MODIS radiances averaged over a 50^2 km ocean grid near the sub-satellite point (±15°lat by ±20°lon area)
- Use GEO provided space count offset
- Perform monthly regressions to derive monthly gains
- Compute timeline trends from monthly gains



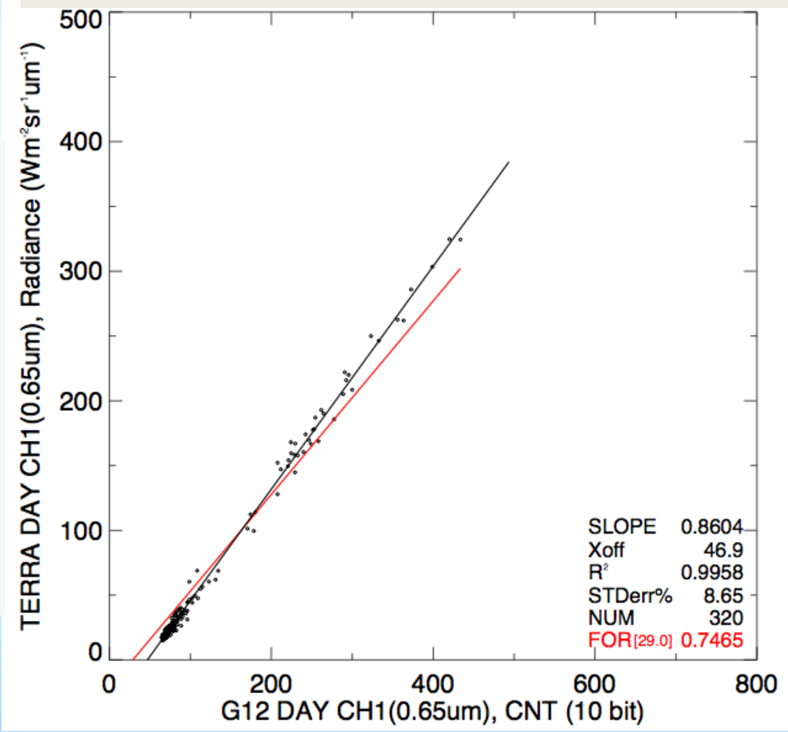


Ray-matching spectral adjustment

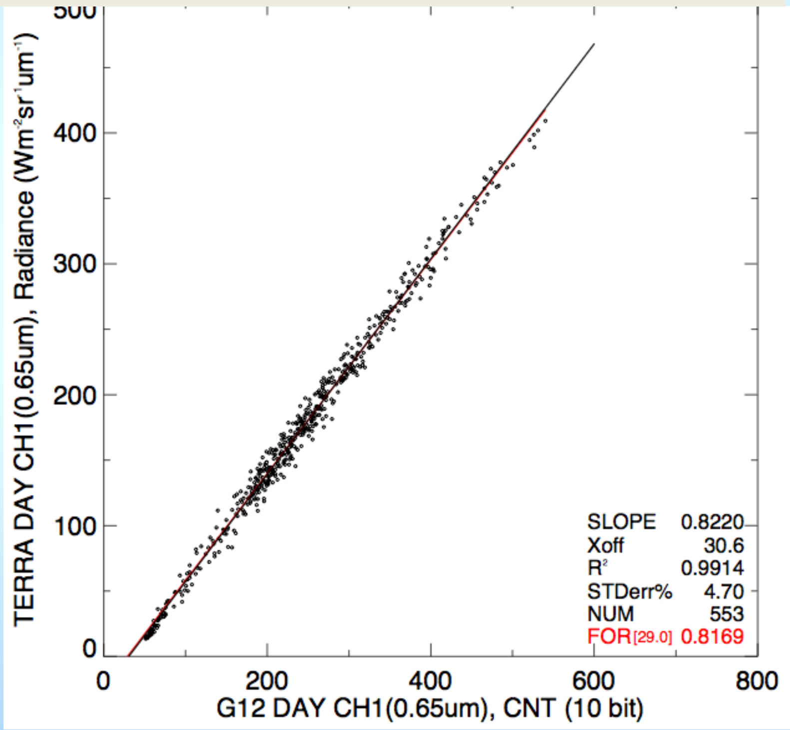
- Use SCIAMACHY-derived pseudo GOES-12 and Aqua-MODIS radiances to adjust GOES-12 radiance as if it had Terra-MODIS spectral response
- Validate by adjusting GOES-12 radiances to Terra-MODIS over ocean and land: **the gains should converge**

No spectral correction

GOES-12/Terra, Sep 2009, Land



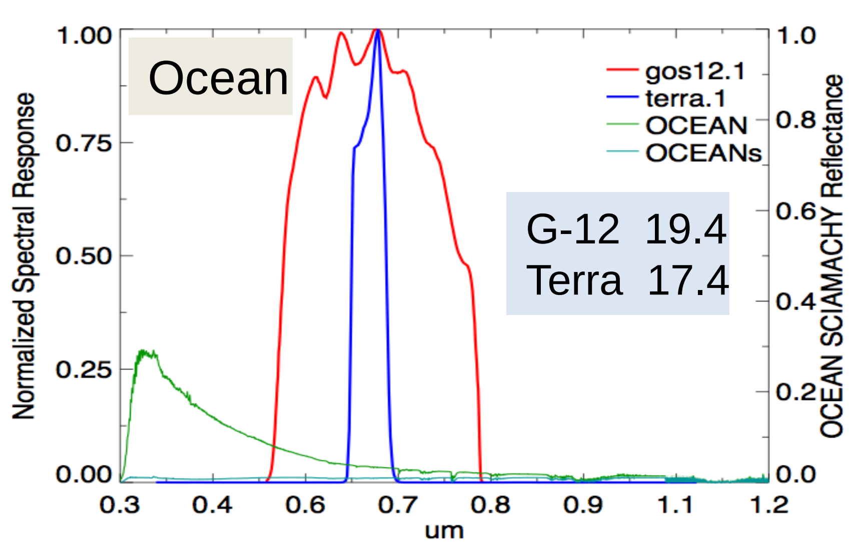
GOES-12/Terra, Sep 2009, Ocean

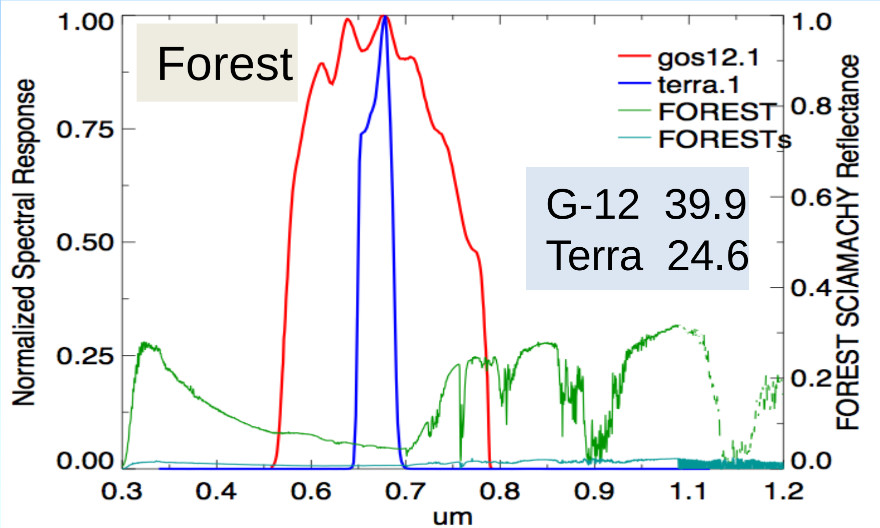


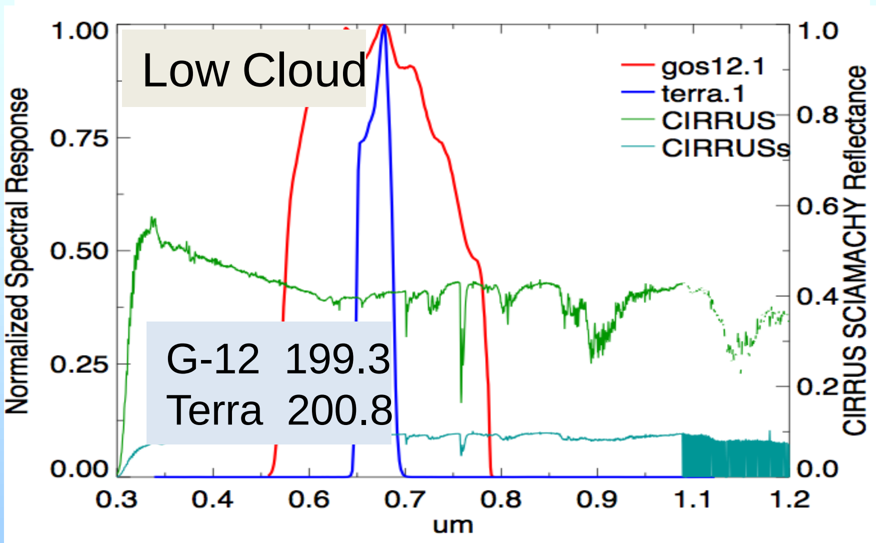
- Gain difference is .8169 for ocean and 0.7465 for land, a 9.4% difference
- Space count is 30.6 for ocean and 46.9 for land, a 16 count difference

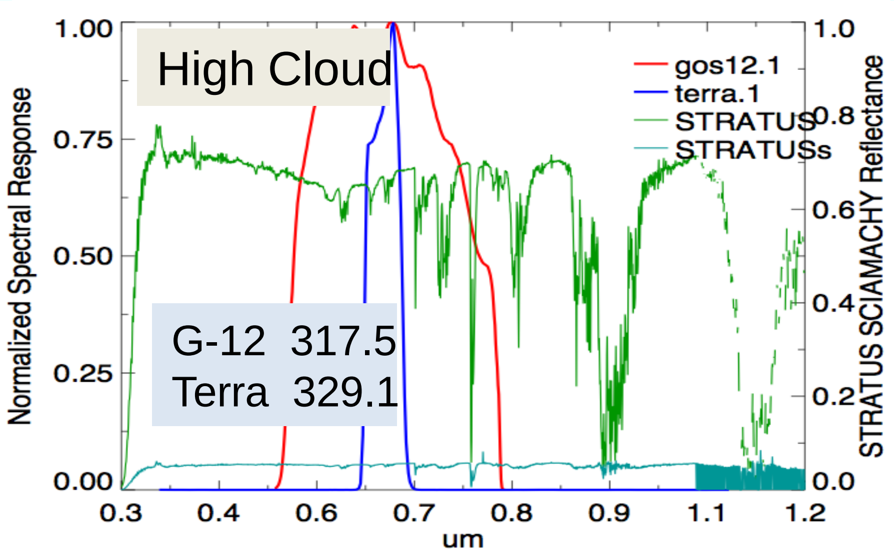
SCIAMACHY reflectances

• SCIAMACHY pseudo radiances in blue boxes



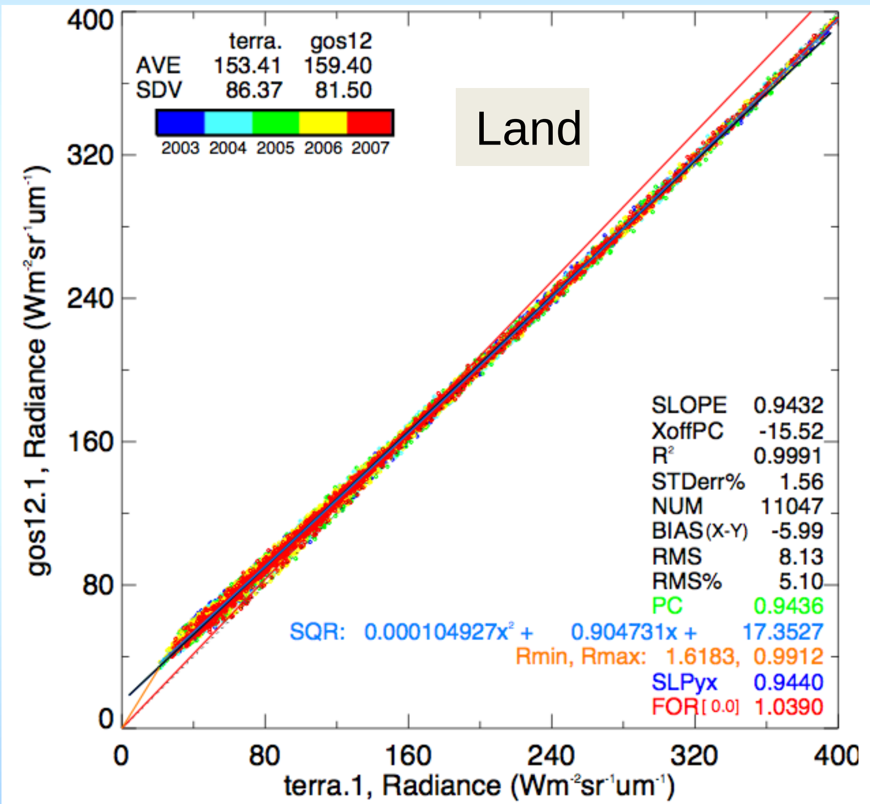


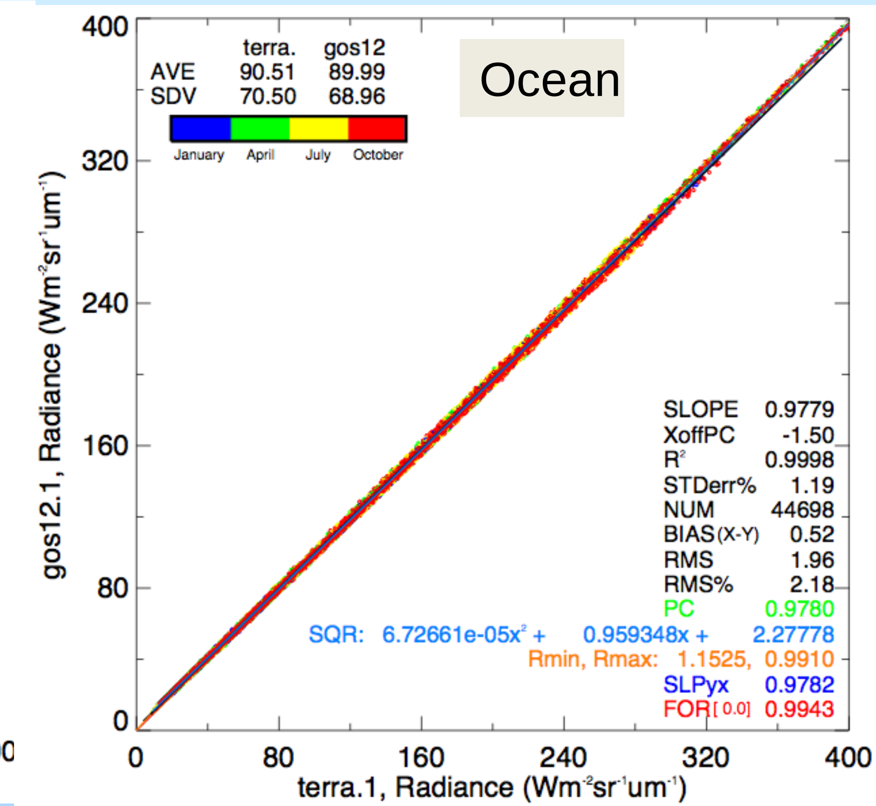




SCIAMACHY Pseudo Radiances

- Use all SCIAMACHY footprint that fall within the GEO/LEO equatorial domain
- Derive spectral correction using cubic fit for land and ocean separately

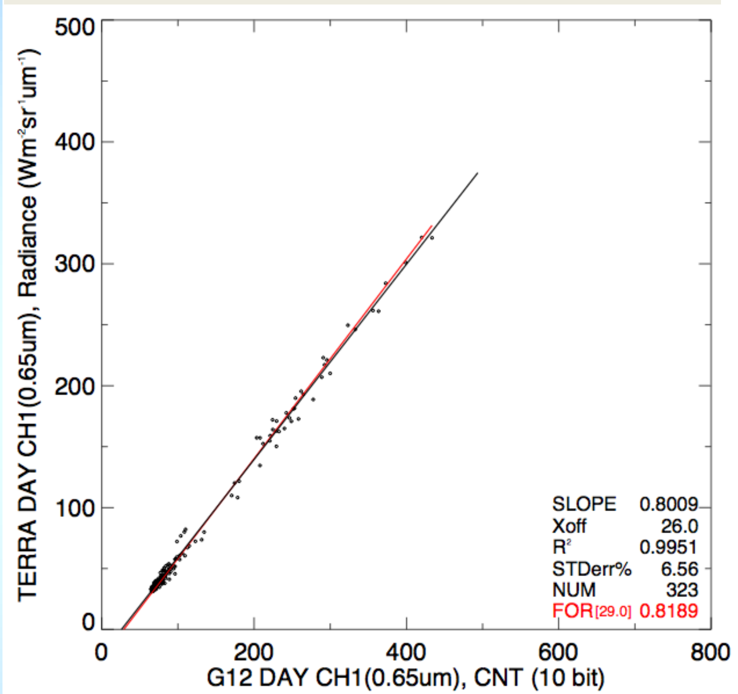




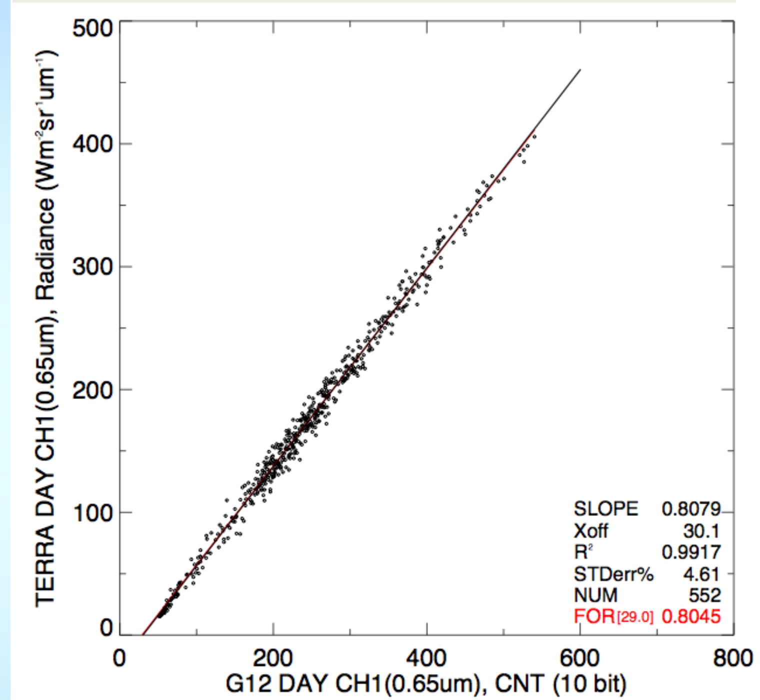
Ray-matching spectral adjustment

With spectral correction

GOES-12/Terra, Sep 2009, Land



GOES-12/Terra, Sep 2009, Ocean

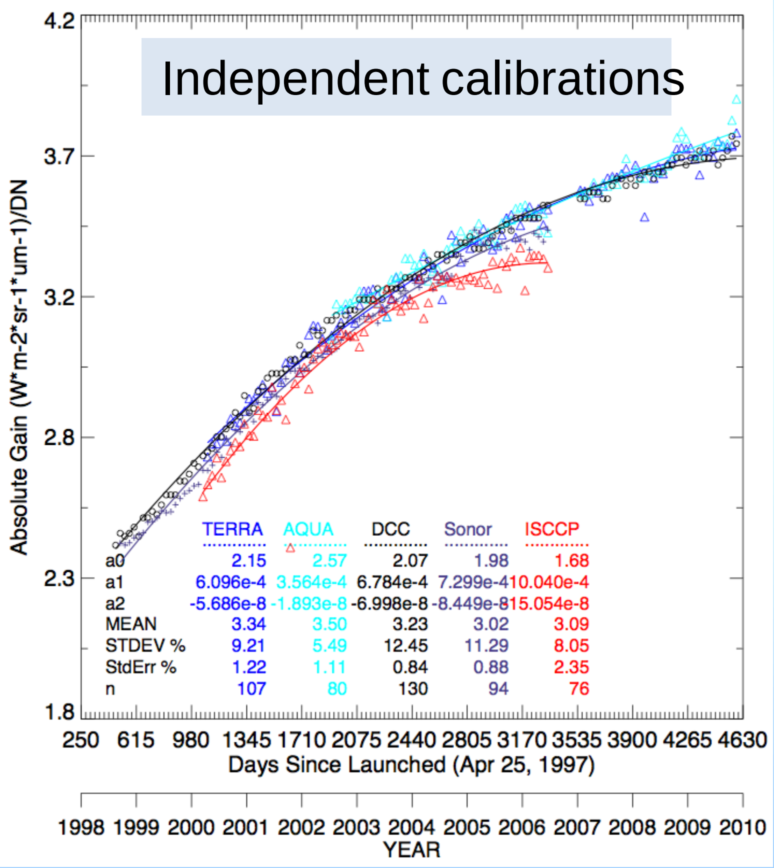


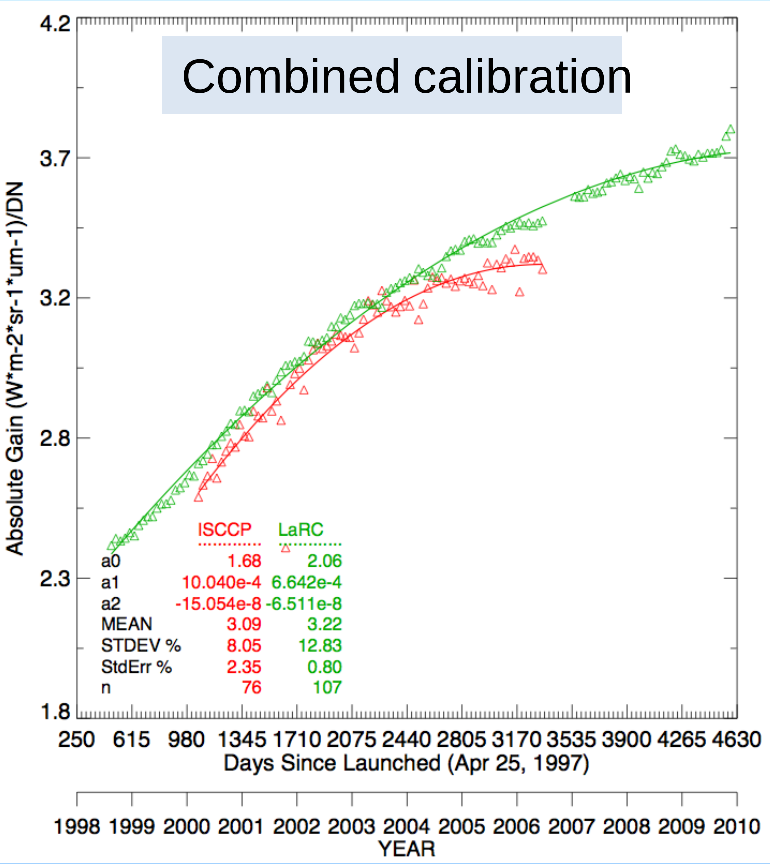
- Gain difference is 0.805 for ocean and 0.819 for land, ~1.7% difference (9.4%)
- Space count is 30.1 for ocean and 26.0 for land, ~ 4 count difference (16)

- Only use ocean geo-type for ray-matching, since spectral correction is minimal

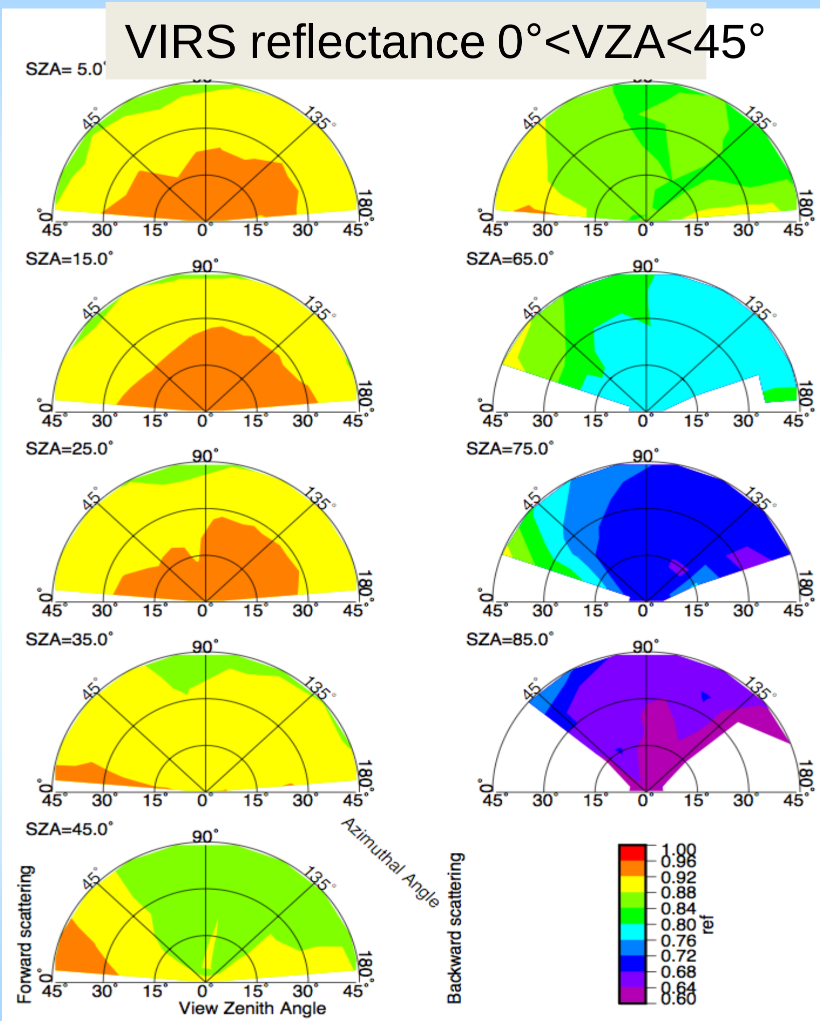
Multi-method GOES-10 calibration

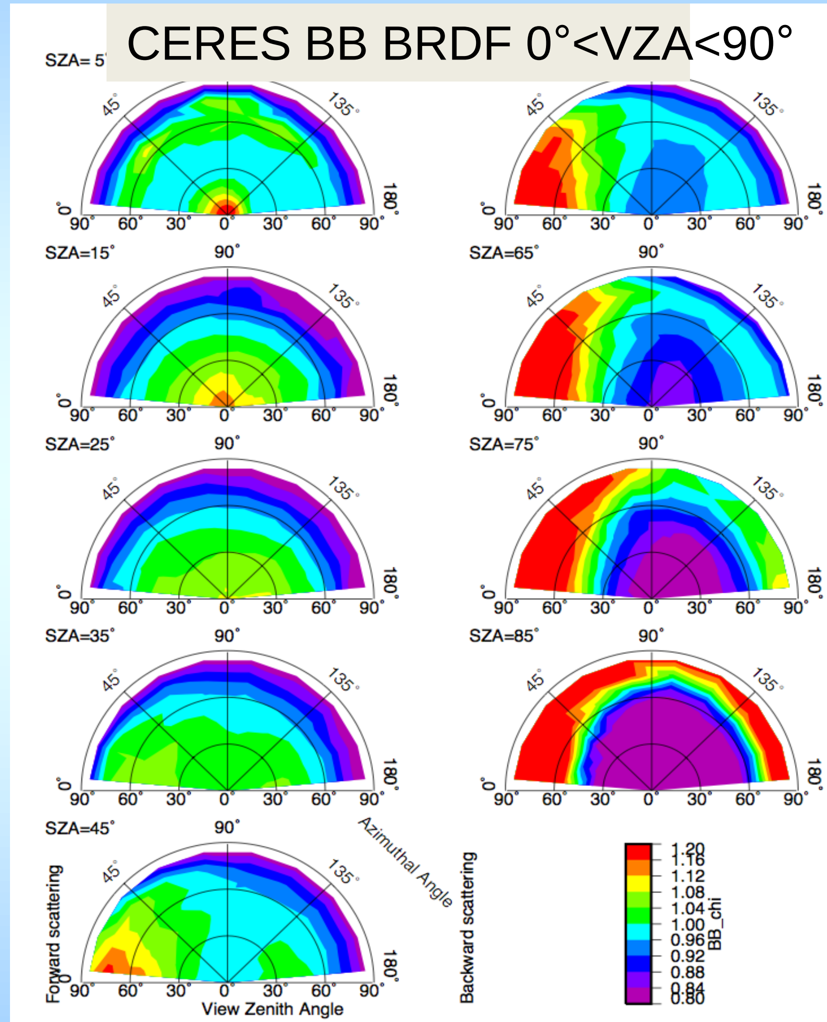
- All methods GOES-12/Terra, GOES-12/Aqua ray-matching, desert and DCC calibration are independent referenced to Aqua-MODIS
- Combine methods by weighting inverse of the standard error of the regression





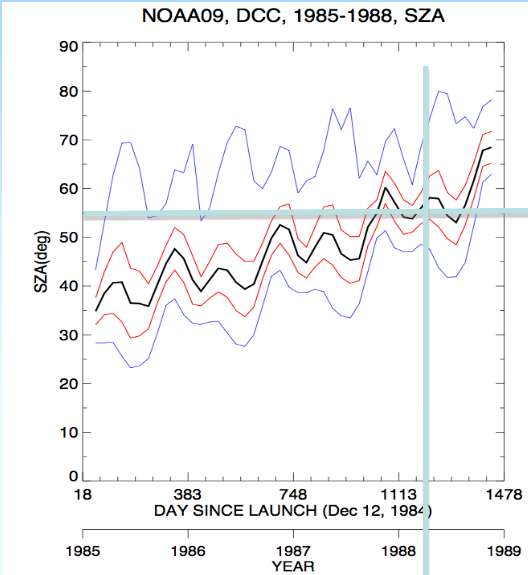
Construct visible DCC ADM models

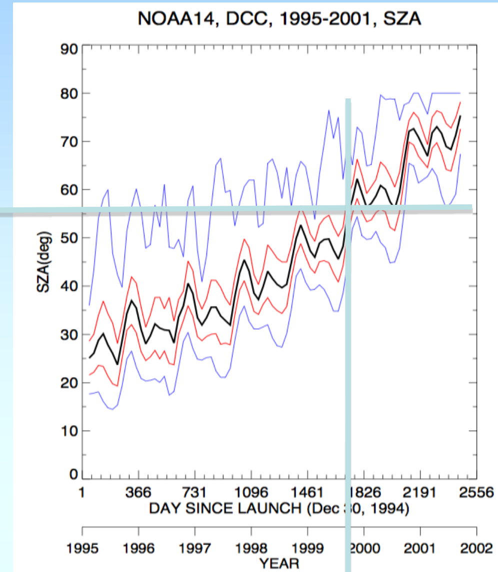


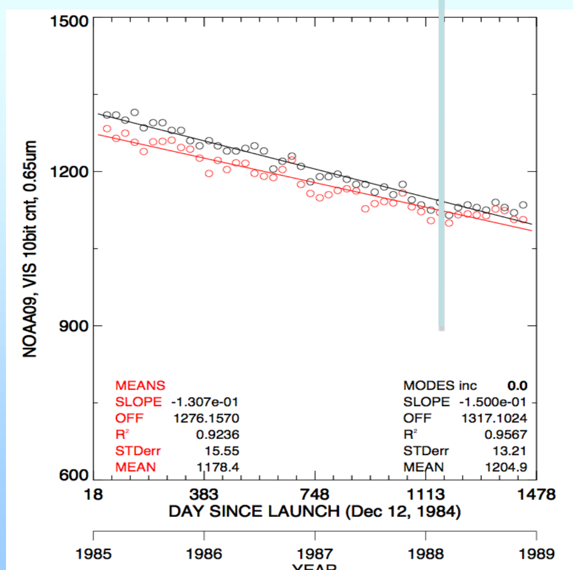


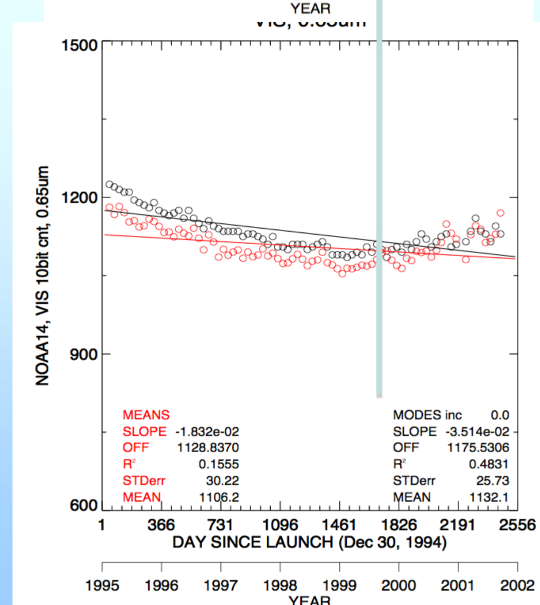
- Work in progress: Preliminary VIRS models to be tested
- Following results use CERES BDRF

AVHRR DCC calibration





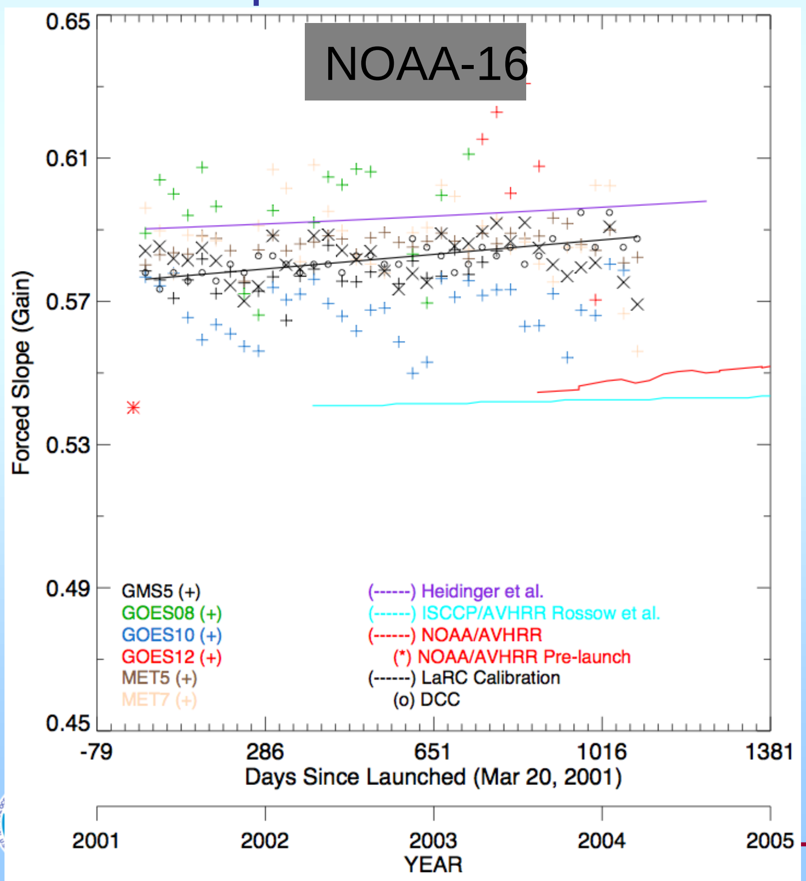


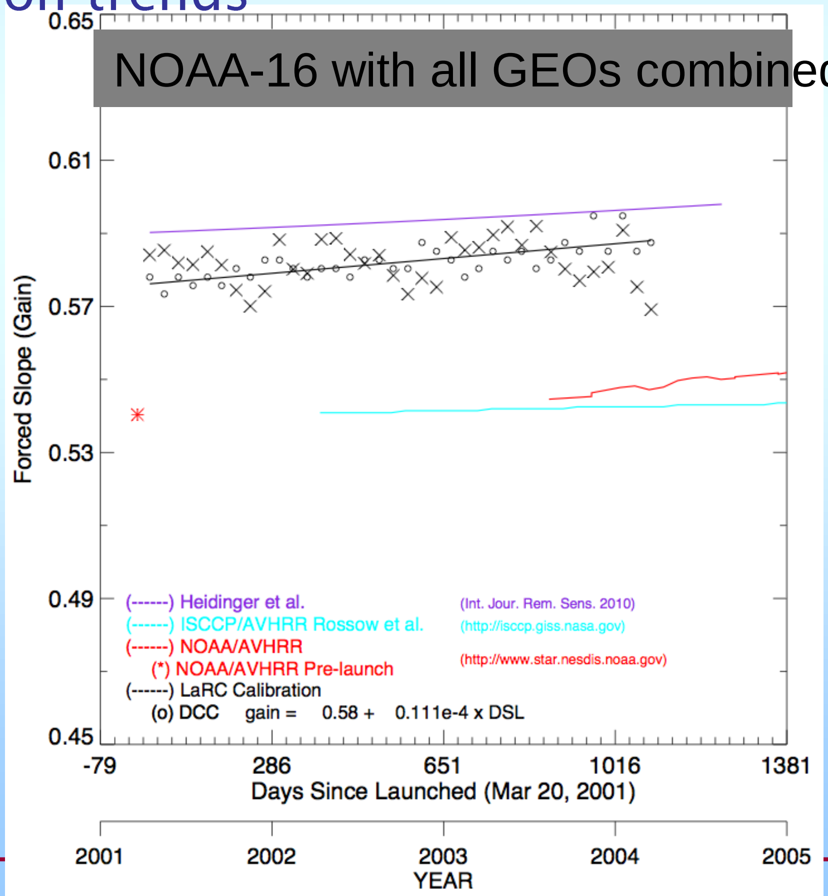


- Currently use a threshold of SZA=55°
- CERES BDRF is broadband and may have more absorption then the visible window channel

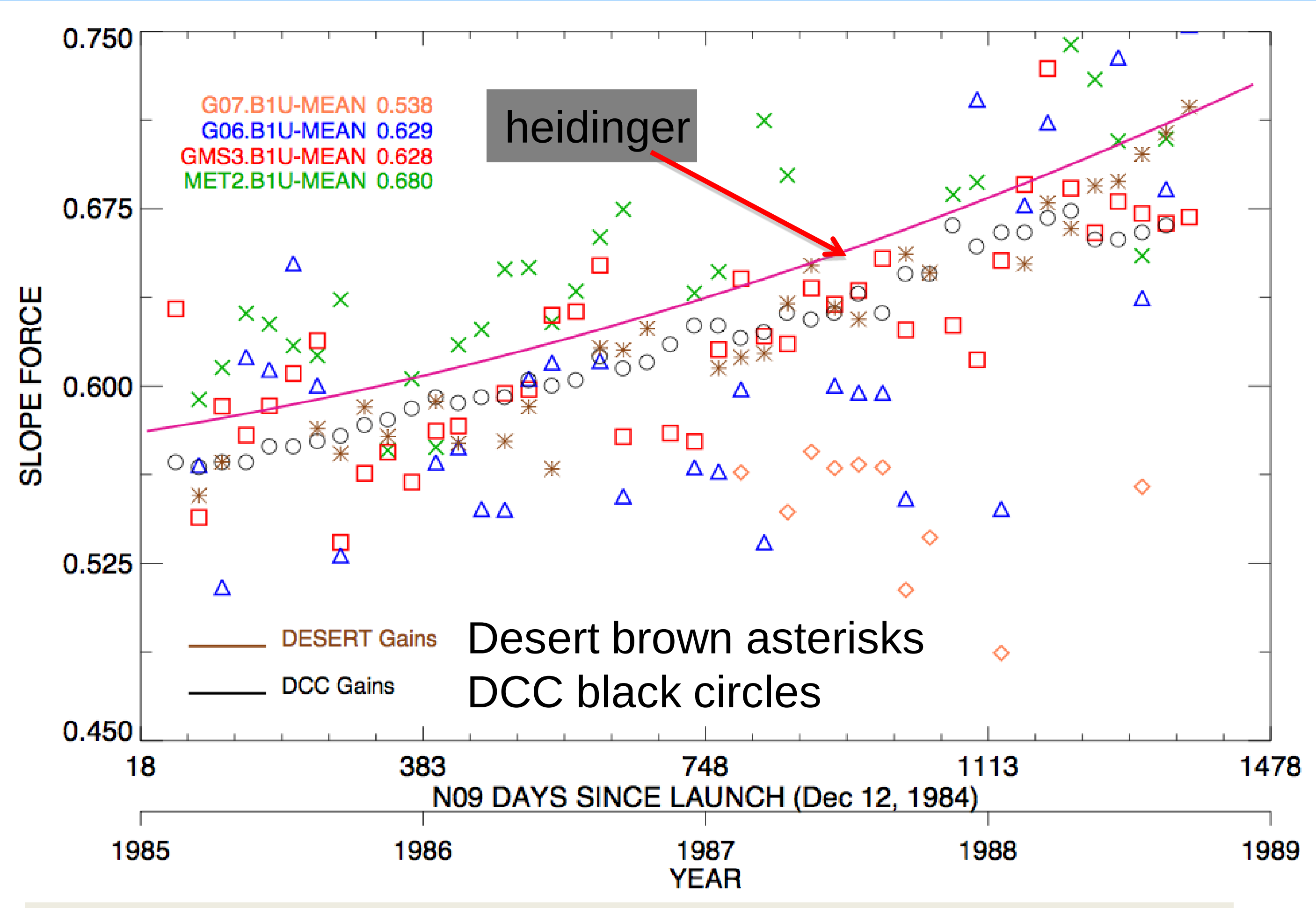
NOAA calibration method

- Use DCC and desert to calibrate NOAA-AVHRR
  - Methods hindered by degradation of NOAA orbits
- Use GEO as independent references
  - Ray-match all simultaneous GEOs with a given NOAA AVHRR
  - Compare to known calibration trends



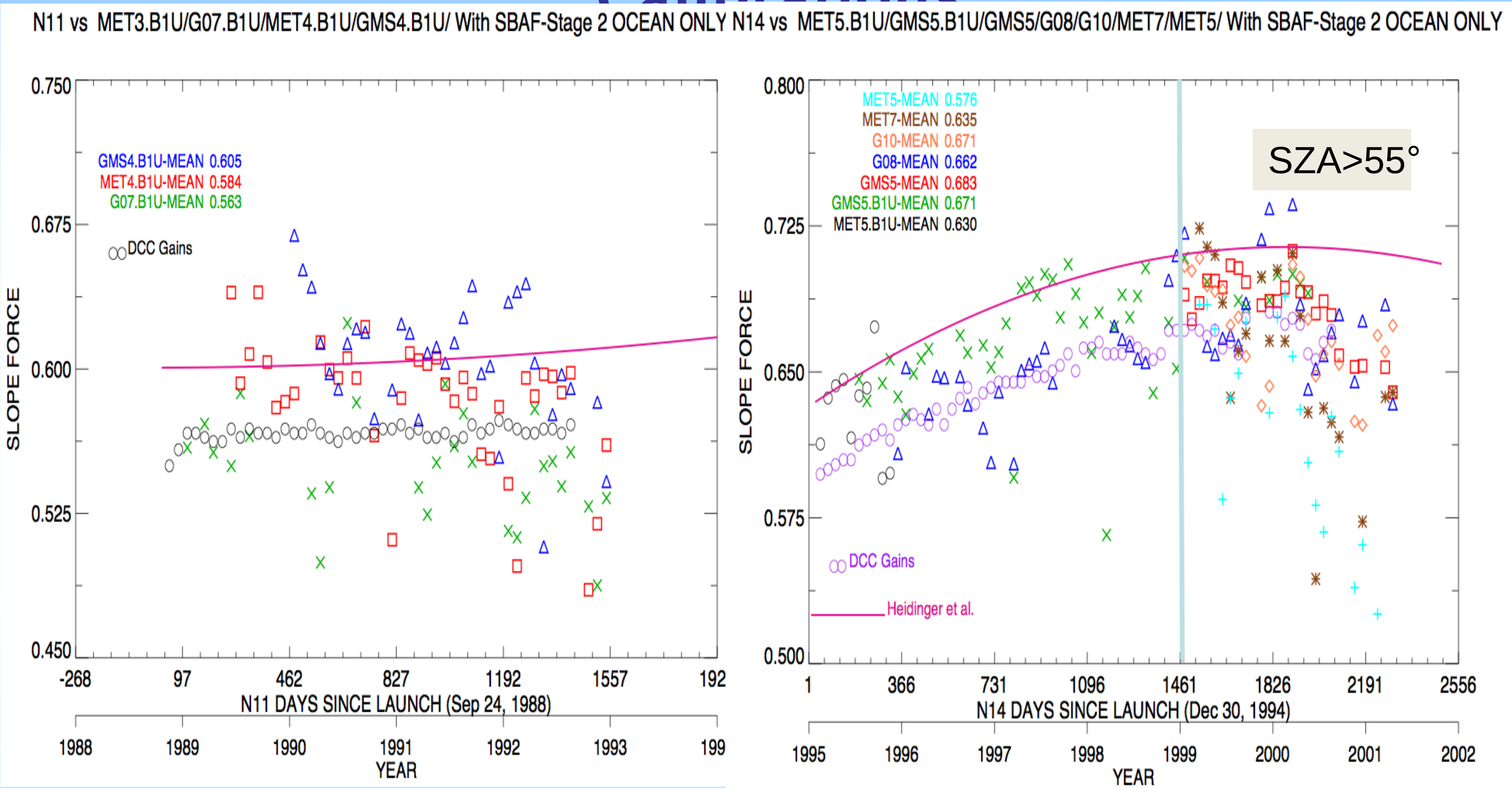


NOAA-9 AVHRR calibration



- Note the consistency between DCC and desert calibration
- Preliminary desert result using VIRS model, DCC to as SZA<55°
- Some GEOs need further investigation

Preliminary N11 and N14 Channel-1 Calibrations



- LaRC ~3% lower than Heidinger in absolute calibration
- Similar temporal trends as Heidinger
- Average of all GEO/AVHRR gains is similar to DCC trends

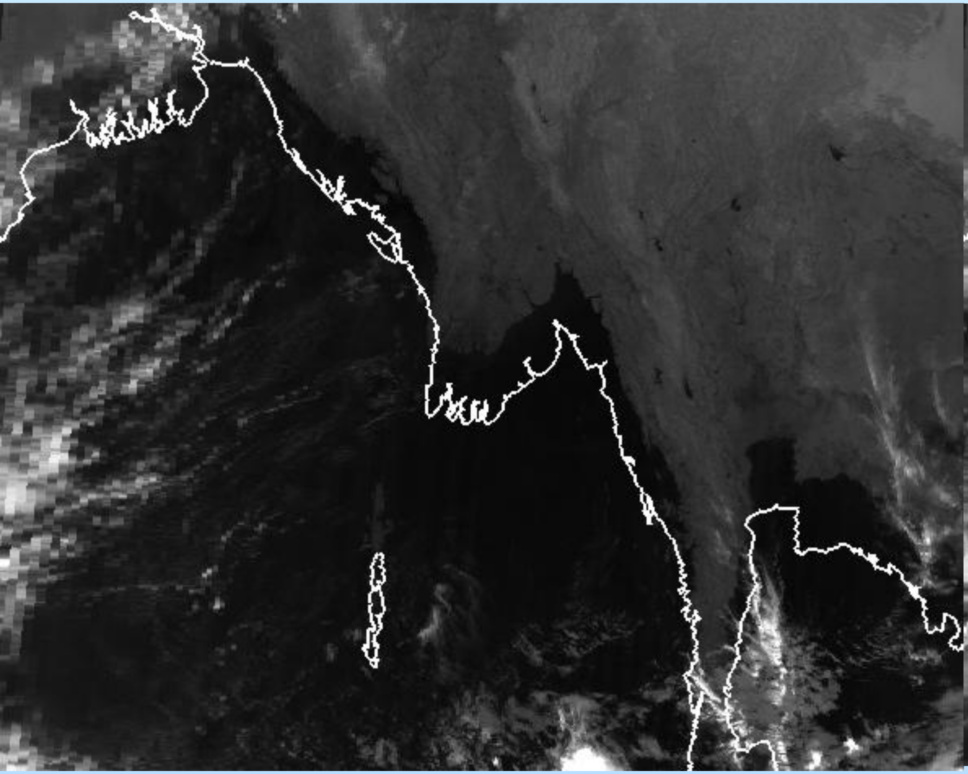
Cloud Analysis Approach

- Calibrate sensors
- Re-navigate all sensors using known locations
- Destripe 3.75-μm channels when necessary
- Adapt CERES Ed4 mask to AVHRR (0.65, 0.86, 3.7, 11, 12 μm, 4 km)
  - Test & tune mask using MODIS (1 km)
    - CERES Ed4 uses AVHRR channels + 1.38, 2.1, 8.5, 13.3 μm
  - Apply to NOAA-18, compare with Aqua MODIS & CALIPSO
    - Make changes as necessary, 1-hr time difference between A-Train & N18
  - Apply to AVHRR back to NOAA-5 (1978-2010)
- Adapt CERES Ed4 Cloud Property Retrieval System to AVHRR
  - Adapt algorithm to limited AVHRR channels
    - Test & refine using MODIS and retest using NOAA-18
      - Test all months
  - Apply to AVHRR back to NOAA-5 (1978-2010)

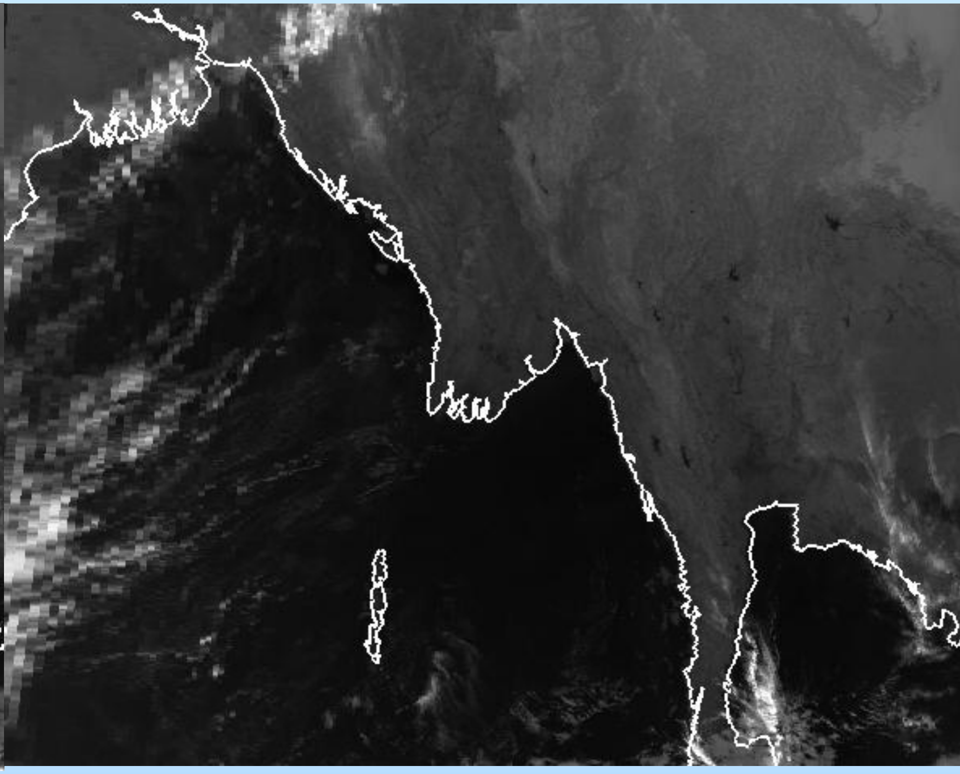
Re-Navigation Example

NOAA-9 1 Dec 1986, 19:50 UTC

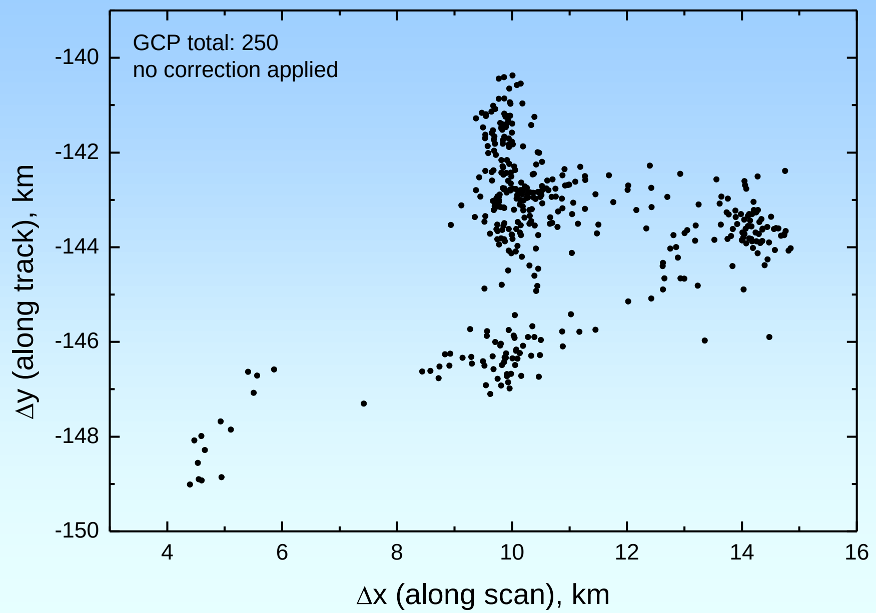
Before



After

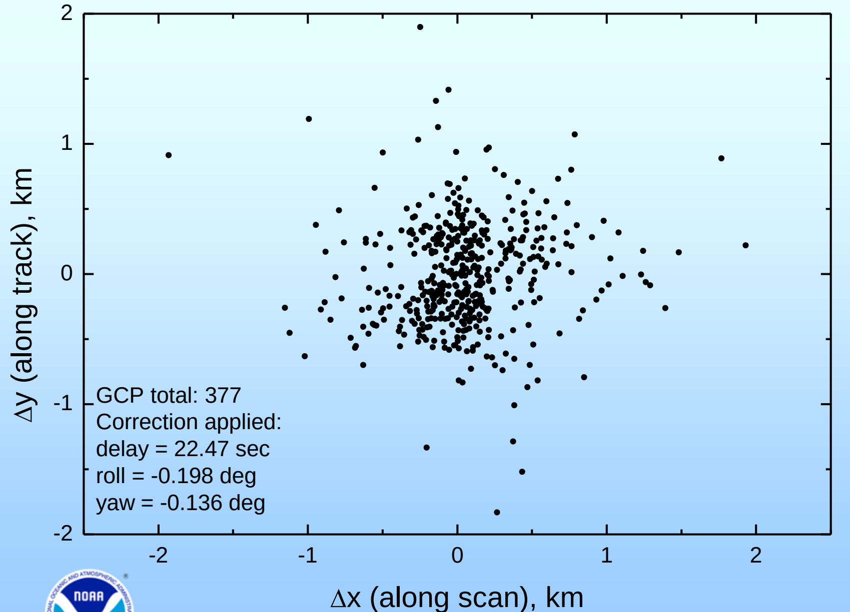


Navigation Correction



AVHRR Channel 2 GAC image displacement relative to a reference MODIS cloud-free composite image. Displacements were calculated by means of image matching at 250 pre-selected cloud-free ground control points. Different groups of points correspond to different cloud-free areas of the AVHRR granule.

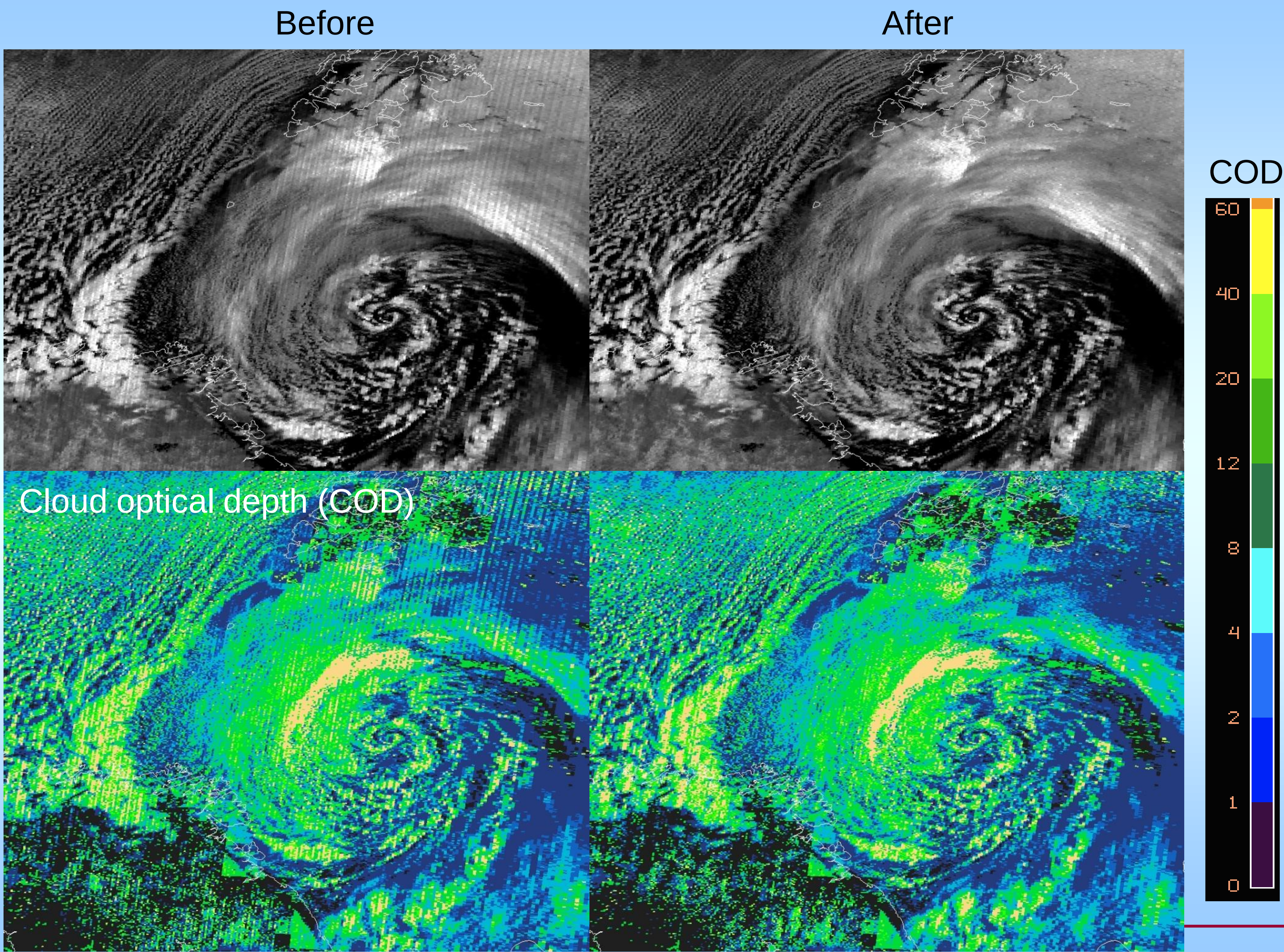
NOAA-9 1986-DEC-01, 19:50 UTC.



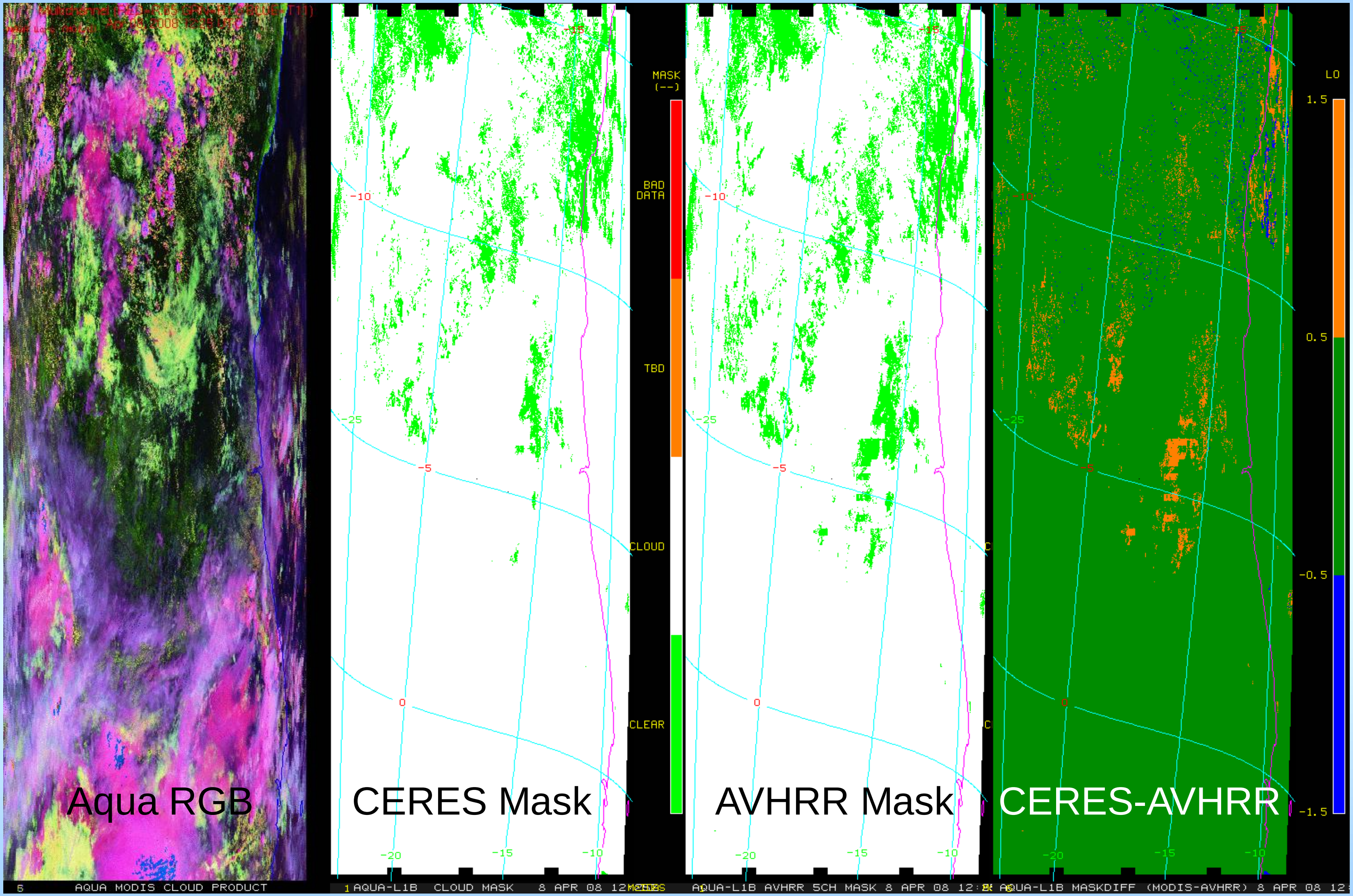
Same set of displacements after the 6-iteration navigation correction process which includes the ortho-correction. The displacement residuals are well below the GAC pixel size of 3x5 km.

by K. Khlopenkov (SSAI), 2011.

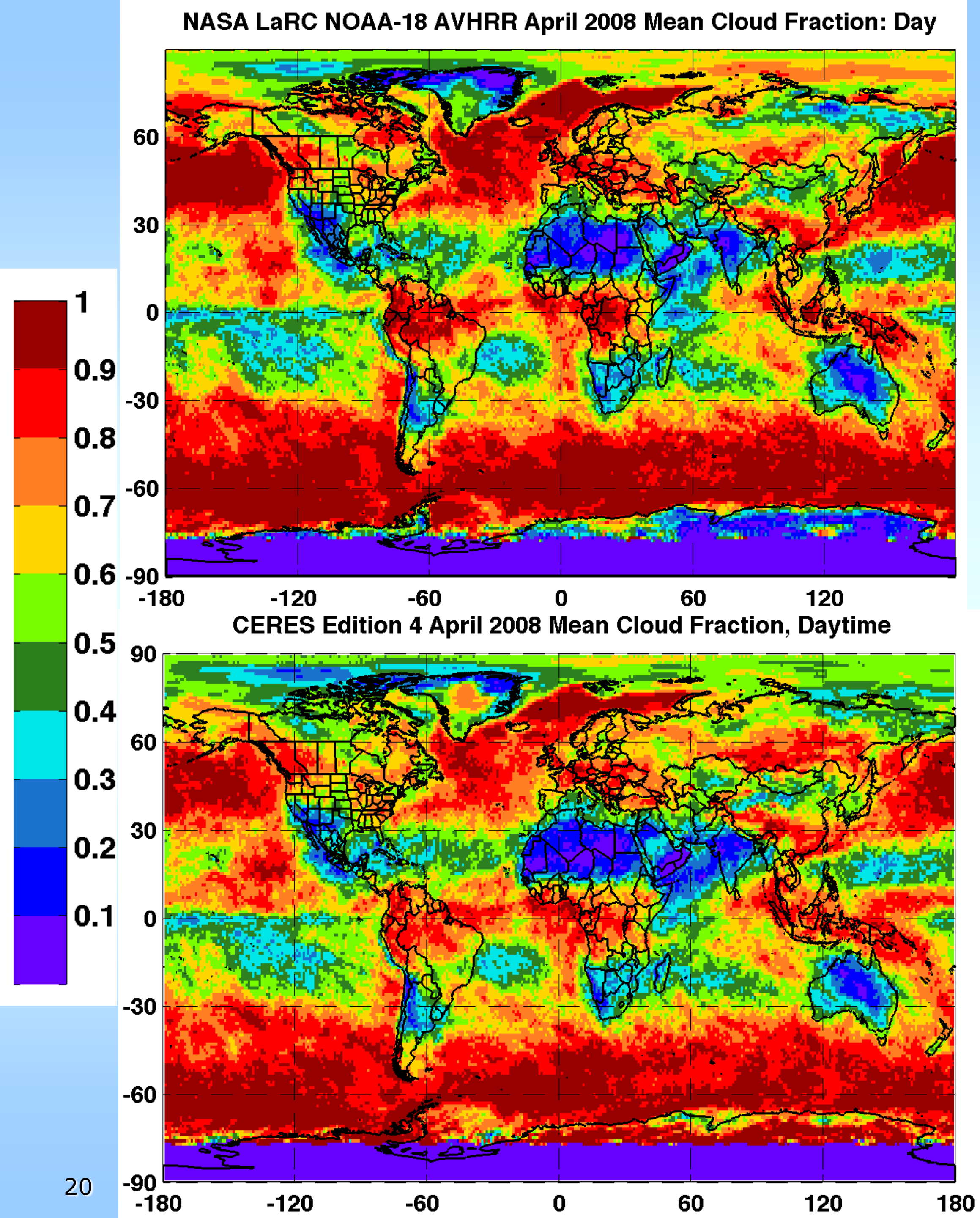
Filtering 3.7-μm Channel: NOAA-9 Night



AVHRR vs CERES Cloud-Mask Results

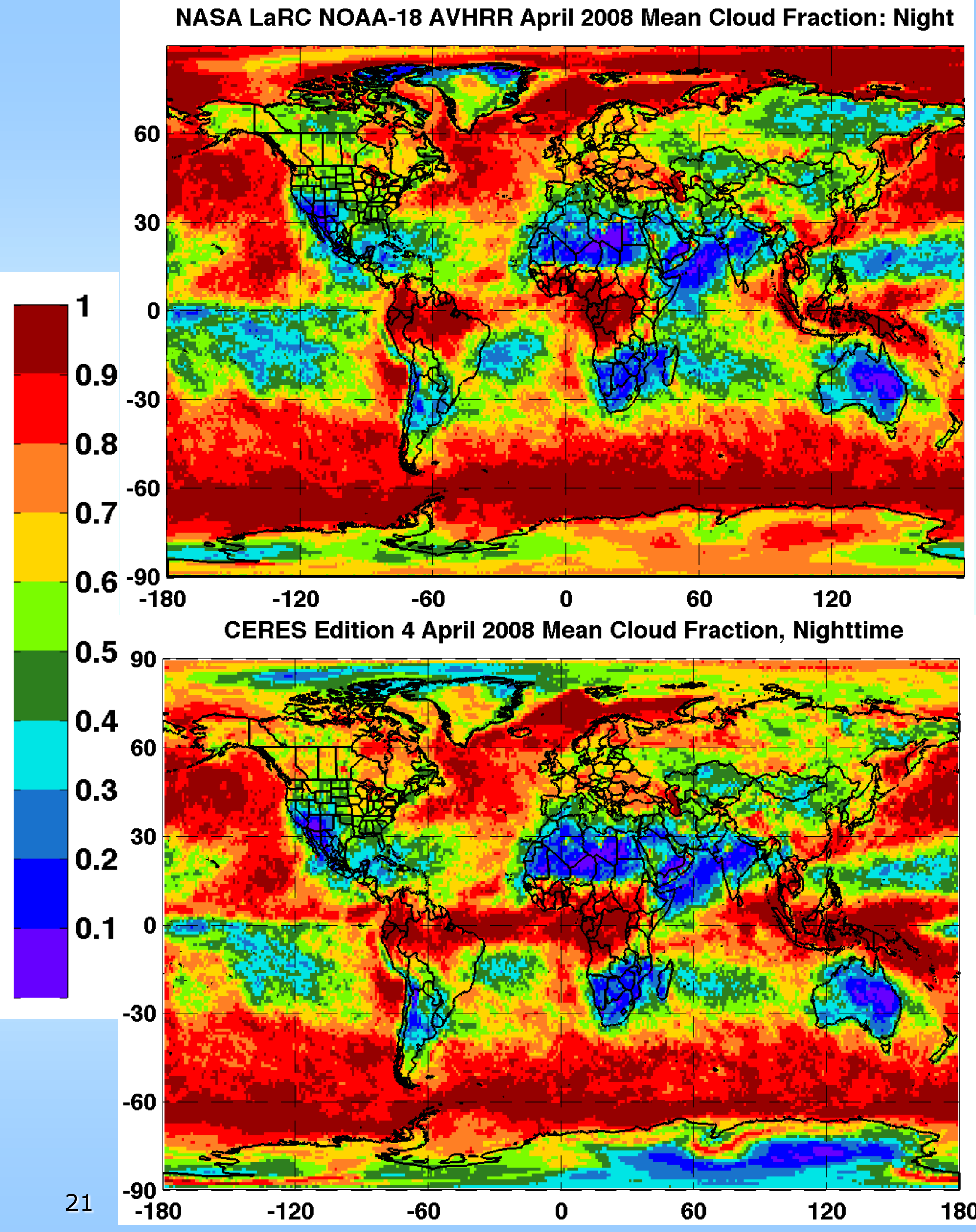


• AVHRR mask still needs tweaking, more in polar regions



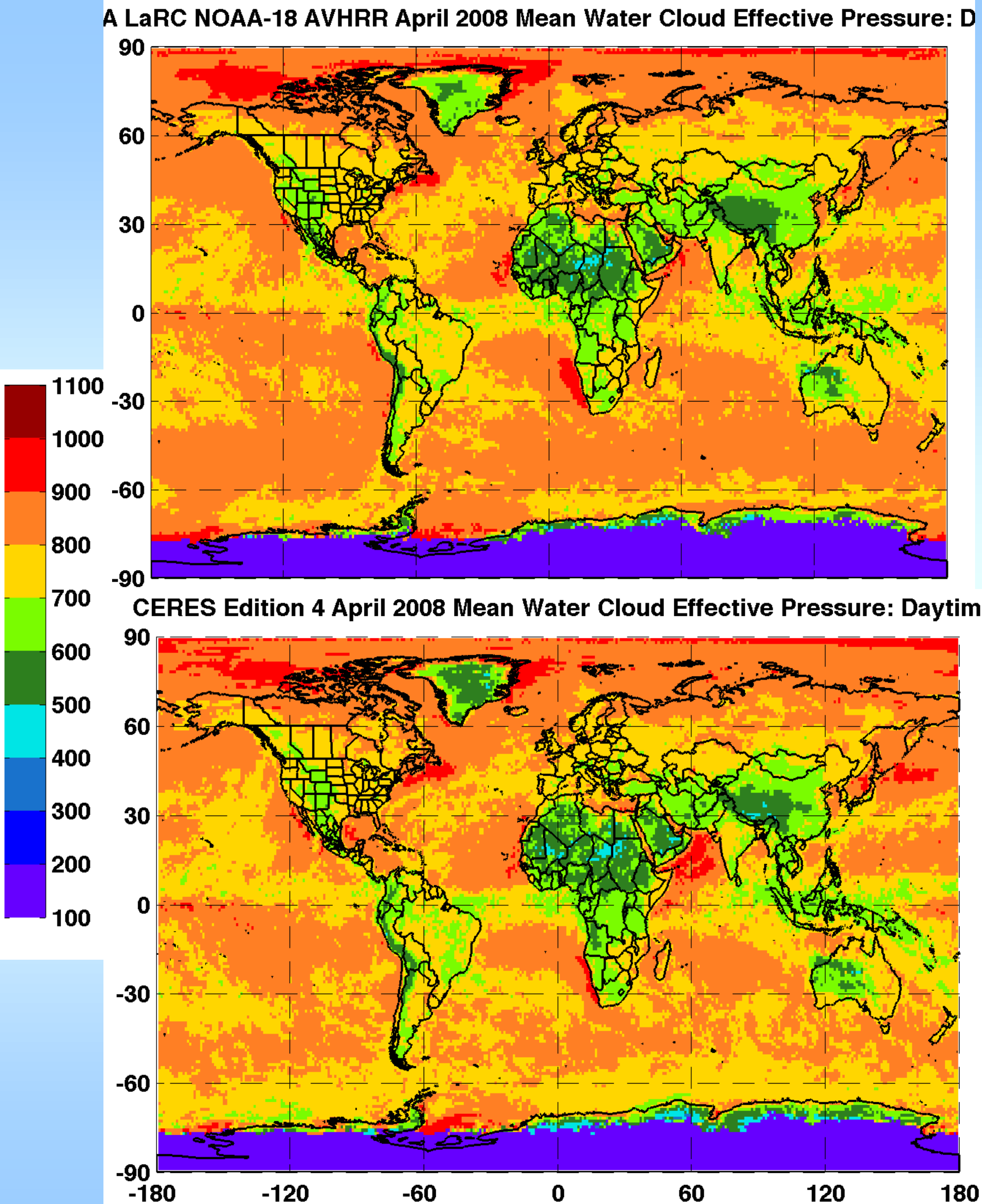
Cloud Fraction
N18 vs Aqua, April 2008
Daytime

- patterns & magnitudes very close except polar regions
- CERES < AVHHR over mid-latitude storm tracks
  - 4-km resolution may reduce hole detection
- CERES > AVHRR over trade Cu & stratCu
  - extra hour (1330-1430 LT) could reduce those cloud types a few percent



Cloud Fraction N18 vs Aqua, April 2008 Night

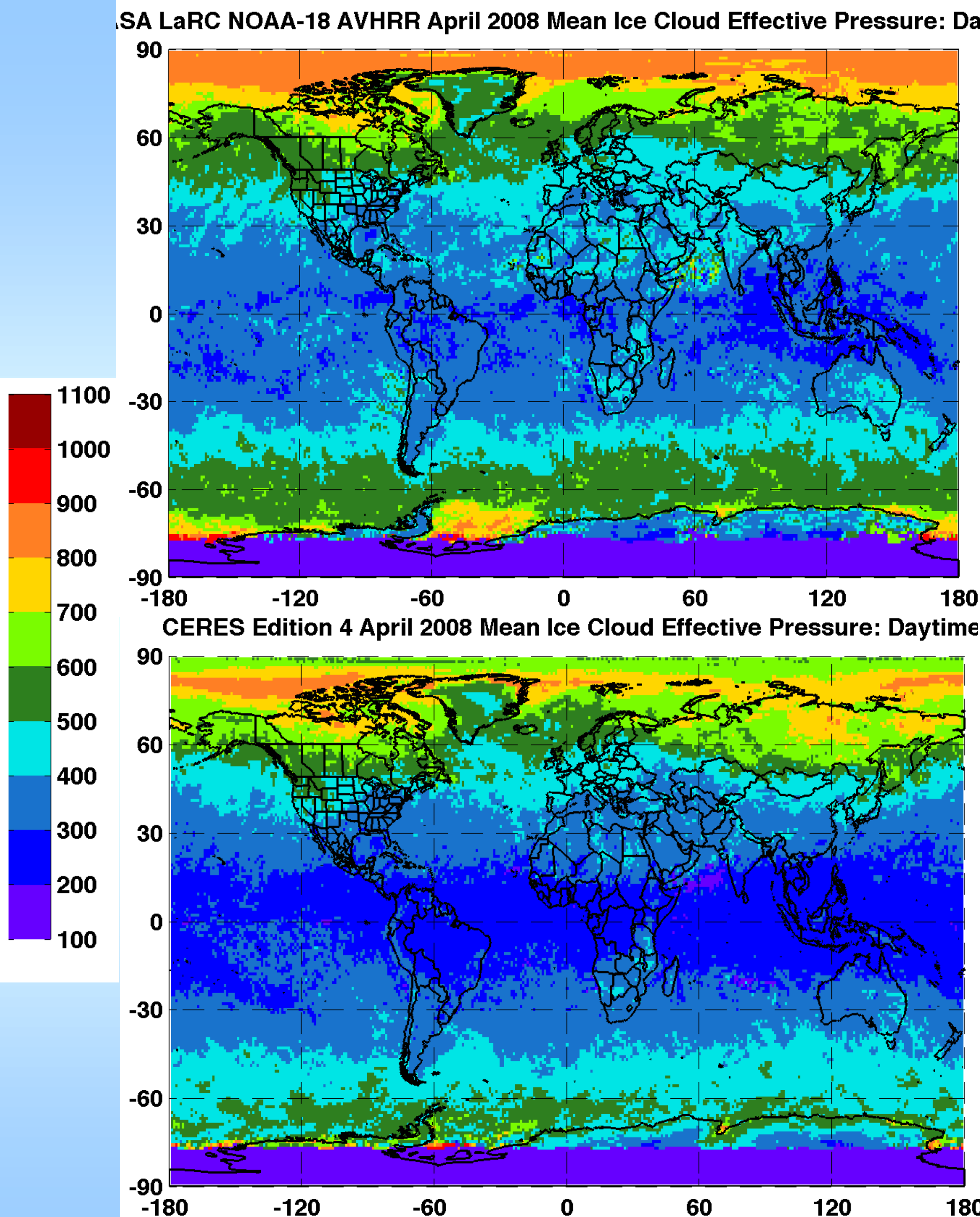
- patterns & magnitudes very close except polar regions
  - poles need work
- CERES < AVHHR over south mid-latitude storm tracks
  - 4-km resolution may reduce hole detection
- CERES > AVHRR over trade Cu & stratCu
  - resolution?
- CERES > AVHRR over tropical convective areas: thin cirrus
  - lack of CO2?
  - sensitivity of T11-T12?



Cloud Effective Pressure N18 vs Aqua, April 2008 Water Cloud, Daytime

- patterns and magnitudes very close
- *p*(CERES) < *p*(AVHHR) over some higher water clouds & vice versa over some near-coast ocean areas

  - constant lapse rate used for AVHRR
  - region-dependent lapse rate used for CERES
  - slightly different sampling



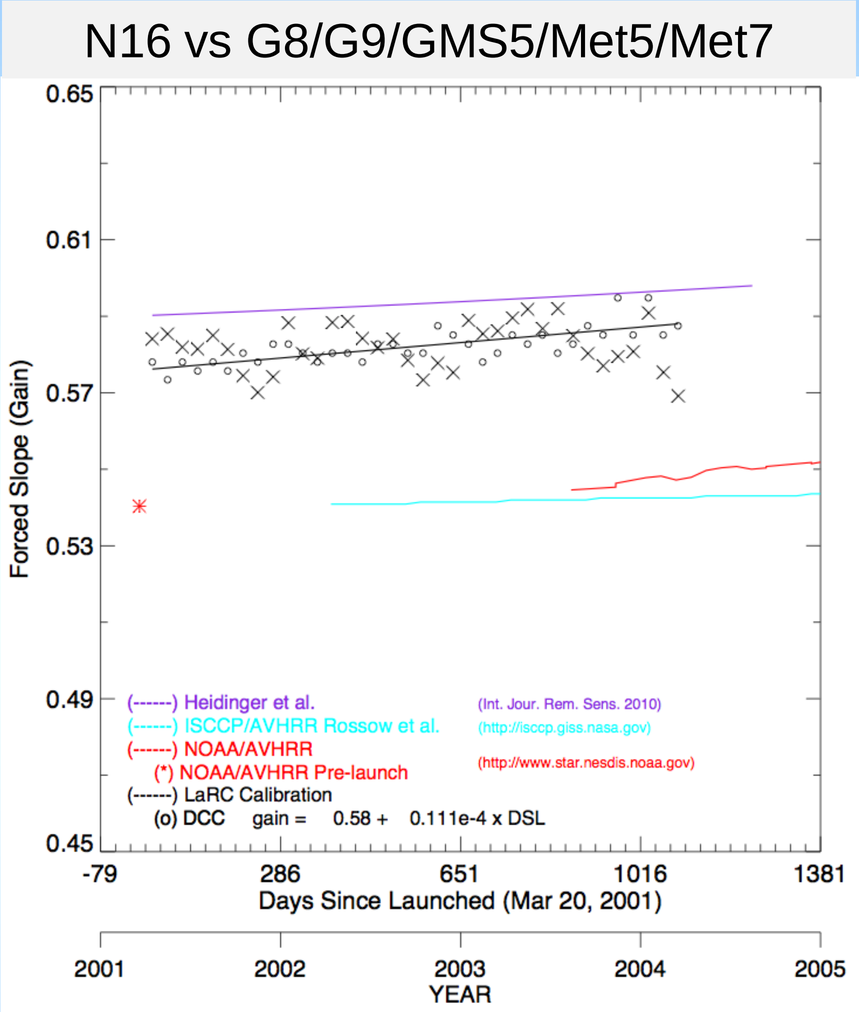
Cloud Effective Pressure N18 vs Aqua, April 2008 Ice Cloud, Daytime

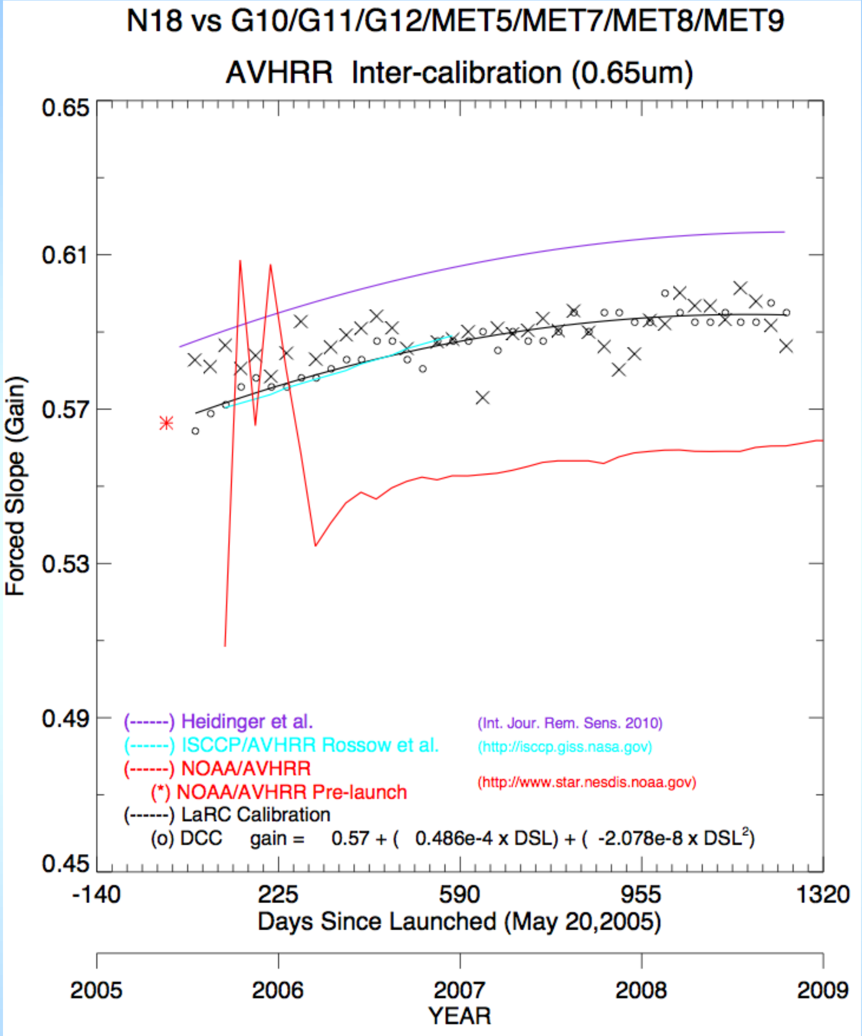
- similar patterns & magnitudes
- *p*(AVHRR) < *p*(CERES) over tropics & polar regions
  - MODIS CO_2 channel has big effect on thin ice cloud height
  - *may need IR only method*

Calibration Validation Strategy

- Validate against direct ray-matching with MODIS for 2000+ period
- Examine trends in cloud optical depths
- Compare with other sources
- Inter-method consistency checks

Preliminary N16 & N18 calibration



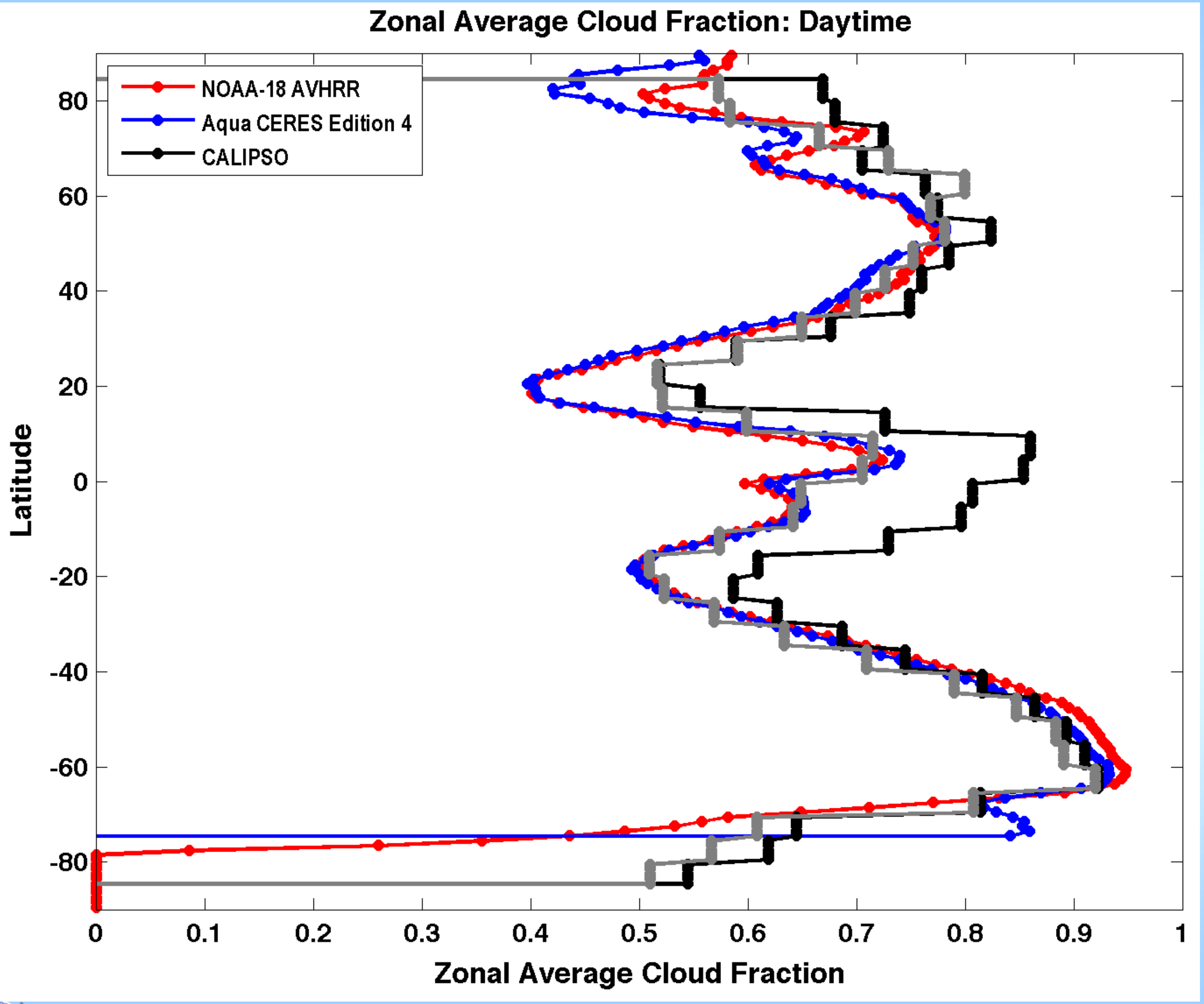


- LaRC N16 ~7% > NOAA gain; N18 ~6% > NOAA gain
- LaRC N16 ~1.8% < Heidinger; N18 ~3.5% < Heidinger
- Similar temporal trends as Heidinger

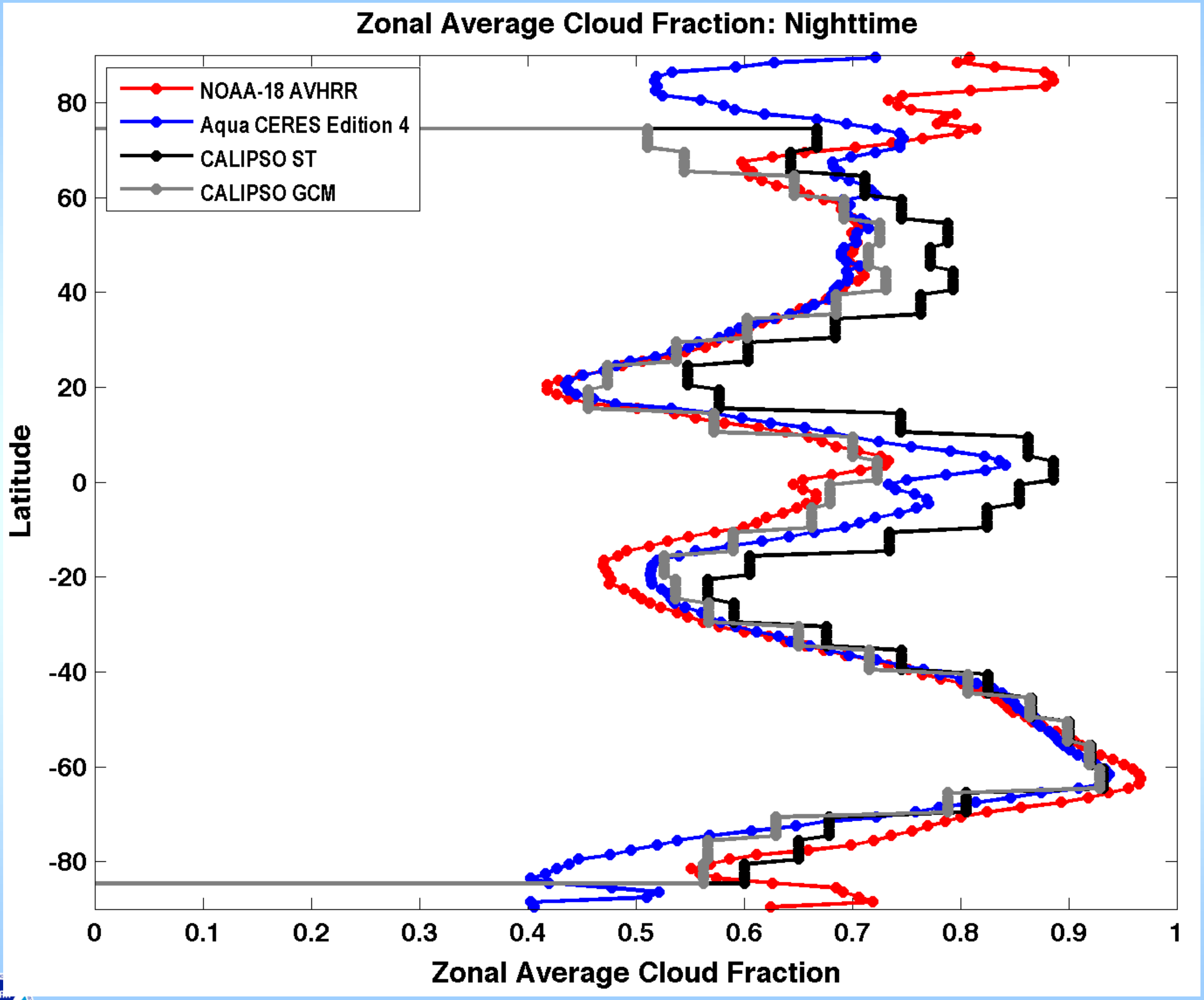
Cloud Validation Strategy

- Compare NOAA 14-19 results w/ CERES & GOES
  - Use closest match (e.g., Aqua w/NOAA-18)
  - Use GOES & Meteosat for off hours
- Compare NOAA-14 -19 w/ARM & CALIPSO data
  - Cloud amounts, heights, & some cloud properties
- Compare long term trends with other climatologies
  - ISCCP, PATMOS-X, surface data
- Examine long-term trends for artifacts due to sensor change

Zonal Cloud Fraction Comparison, Day, April 2008



Zonal Cloud Fraction Comparison, Night, April 2008



Publications & Presentations

- Doelling, D. R., C. Lukashin, P. Minnis, B. Scarino, and D. Morstad, 2011: Spectral reflectance corrections for satellite intercalibrations using SCIAMACHY data. *Geosci. Remote Sens. Lett.*, doi: 10.1109/LGRS.2011.2161751, in press.
- Wu, X., et al., 2011: Assessment of MetOp-A Advanced Very High Resolution Radiometer (AVHRR) Short Wave Infrared channel measurements using Infrared Atmospheric Sounding Interferometer (IASI) observations and line-by-line radiative transfer model simulations. *Remote Sens. Lett.*, submitted.
- Bedka, K., J. Brunner, R. Dworak, W. Feltz, and P. Minnis, 2010: Objective overshooting convective cloud top detection: climatology, product validation, and their relationship with severe weather and aviation hazards. *2010 EUMETSAT Satellite Conference*, Cordoba, Spain, September 20-24.
- Minnis, P. W. L. Smith, Jr., S. Sun-Mack, Y. Chen, D. A. Spangenberg, R. Palikonda, and R. F. Arduini, 2010: Retrieving cloud properties over snow and ice surfaces. *3rd Intl. Symp. Recent Advances in Quantitative Remote Sens.*, Valencia, Spain, September 27-October 1, S3.1.
- Scarino, B., D. R. Doelling, D. Morstad, A. Gopalan, P. Minnis, R. Bhatt, and C. Luckachin, 2010: Absolute calibration of AVHRR visible sensors using SCIAMACHY hyperspectral data and MODIS radiances. *2010 AGU Fall Mtg.*, San Francisco, CA, December 13-17, A13G-0303.
- Morstad, D., D. R. Doeliing, B. Scarino, A. Gopalan, R. Bhatt, and P. Minnis, 2010: AVHRR calibration approach that uses ray-matching, invariant desert, and deep convective cloud techniques. *2010 AGU Fall Mtg.*, San Francisco, CA, December 13-17, A13G-0304.

Issues/Risks & Work-Off Plans

- Calibration SZA > 55°
  - Use interpolation/extrapolation and/or push SZA limits
  - Use GEO cal directly

- Polar mask
  - Continue tuning using MODIS as AVHRResolution differences
  - Test effect by degrading MODIS, examine thresholds

- Cloud height
  - Implement regionally dependent lapse rates
  - Use IR only retrievals for thin cirrus

- Polar cloud retrievals
  - Continue refining 0.65/0.86-μm methods vs 1.24/2.1 μm methods

Schedule

Year 1
- Completed semi-automated integration software for DCCT & NSRT calibrations
- Completed preliminary AVHRR calibrations (N9, 11, 14,16, 18)
- Evaluated MODIS data to establish references and uncertainties
- Perform desert site calibrations
- Calibrated GEOsat calibrations (1985-present)
- Set up global automated cloud analysis system to apply to AVHRR
- Developed automated navigation & filtering methods
- Analyze initial AVHRR data (N18)
- Computed SRF ratios from SCHIAMCHY data

Year 2
- Refine polar retrieval method to incorporate improved snow albedo and SIST
- Perform final calibrations AVHRR (N9-N19)
- Set up website to provide calibration and cloud results
- Coordinate with NCDC to archive results
- Perform cloud retrievals on AVHRR data (N9, N11, N14- N19)
- Compare desert site calibrations to NSRT-DCCT results
- Document GEOsat and AVHRR calibrations (1991-2010)

Year 3
- Update MODIS calibrations
- Complete record of AVHRR and GEOsat calibrations to 1978
- Complete cloud analyses for AVHRR through 1978 (N5 – N10)
- Complete error analyses & validation
- Provide final reports on TCDR and FCDRs
- Document results in journal articles

Transition Plan

- DOCUMENTATION
  - Climate Algorithm Theoretical Basis Document (C-ATBD)
    - Delivery early 2013
  - Data Flow Chart and Maturity Matrix
    - Next page
- DATA SET(S)
  - Product output in NetCDF-4
  - Units, missing value, valid range, coordinates, scale factor, long name specified as attributes in metadata
  - 1 orbit of Level 2 products=13000x409 pixels

  ~450,000 AVHRR orbits (1978-2010) * 100 Mb/orbit

  45 TB of GAC 4 km pixel level retrieval output

- SOURCE CODE
  - Old NASA ATBD, algorithm mostly described in Minnis et al. (*TGRS*, 2008, 2011)
  - Code is currently under development and evolving so documentation will follow
  - Mixture of C and Fortran with shell script driver
  - README (none)

v. June 2010

CDR Maturity Matrix

Climate Data Record (CDR) Maturity Matrix

Maturity	Software Readiness	Metadata	Documentation	Product Validation	Public Access	Utility
1	Conceptual development	Little or none	Draft Climate Algorithm Theoretical Basis Document (C-ATBD); paper on algorithm submitted	Little or None	Restricted to a select few	Little or none
2	Significant code changes expected	Research grade	C-ATBD Version 1+ ; paper on algorithm reviewed	Minimal	Limited data availability to develop familiarity	Limited or ongoing
3	Moderate code changes expected	Research grade; Meets int'l standards: ISO or FGDC for collection; netCDF for file	Public C-ATBD; Peer-reviewed publication on algorithm	Uncertainty estimated for select locations/times	Data and source code archived and available; caveats required for use.	Assessments have demonstrated positive value.
4	Some code changes expected	Exists at file and collection level. Stable. Allows provenance tracking and reproducibility of dataset. Meets international standards for dataset	Public C-ATBD; Draft Operational Algorithm Description (OAD); Peer-reviewed publication on algorithm; paper on product submitted	Uncertainty estimated over widely distributed times/location by multiple investigators; Differences understood.	Data and source code archived and publicly available; uncertainty estimates provided; Known issues public	May be used in applications; assessments demonstrating positive value.
5	Minimal code changes expected; Stable, portable and reproducible	Complete at file and collection level. Stable. Allows provenance tracking and reproducibility of dataset. Meets international standards for dataset	Public C-ATBD, Review version of OAD, Peer-reviewed publications on algorithm and product	Consistent uncertainties estimated over most environmental conditions by multiple investigators	Record is archived and publicly available with associated uncertainty estimate; Known issues public. Periodically updated	May be used in applications by other investigators; assessments demonstrating positive value
6	No code changes expected; Stable and reproducible; portable and operationally efficient	Updated and complete at file and collection level. Stable. Allows provenance tracking and reproducibility of dataset. Meets current international standards for dataset	Public C-ATBD and OAD; Multiple peer reviewed publications on algortihm and product	Observation strategy designed to reveal systematic errors through independent cross-checks, open inspection, and continuous interrogation; quantified errors	Record is publicly available from Long-Term archive; Regularly updated	Used in published applications; may be used by industry; assessments demonstrating positive value

1 & 2	Research
3 & 4	IOC
5 & 6	FOC

Benefit to the Science Community

- Climate modeling & monitoring community
  - GEWEX cloud observation intercomparison (Stubenrauch et al., 2011?)
  - Cloud frac/height comparisons w/GCMs (Zhang et al., *JGR*, 2005)
  - Cloud IWP comparisons w/GCMs (Waliser et al., *JGR*, 2009)
- Datasets from our study will provide calibrations & uncertainty estimates for users of AVHRR radiances and cloud data
  - Requests for calibration information are common
- Facilitates development of other CDRs requiring cloud-free scenes or those requiring cloud information
  - E.g., regional surface temperature trends, UTH studies (Luo), ERB (Kato)
- International scientists & grad students (no advertising)
  - Requests for old cloud data from Chile, Israel, Argentina, Brazil, etc.
  - 3-5 requests per year from grad students

Benefit to Society (anecdotal)

- Indirect climate benefits already mentioned
- Energy sector
  - At least, one company currently using our historical GOES pixel level cloud data for solar collector siting, longer record -> better stats
- Transportation (potential)
  - Aviation, improved statistics on aircraft icing conditions can be developed from long-term cloud data (NTSB has requested archived cloud properties in past)
  - Aviation and ground transport, statistics on fog for highway & airport planning, land use, etc.
- Communications
  - A cell phone company used our GOES pixel data for studying transmission of signals, longer AVHRR record -> better stats
- Public
  - Appalachian Mtn Club requested historical cloud height data to study effect of cloud ceiling on Mt Washington tree line
  - NASA S'COOL program: direct use of sat cloud data by K-12

Resources

- Number of personnel employed for project
  - *2.8 FTE*
- Key equipment or observatories used
  - NASA Langley Research Center, AMI computer
  - NASA Ames Columbia Supercomputer
- Key collaborating projects or personnel
  - NASA CERES (Minnis, Doelling)
  - NOAA GSICS activity, Co-I: D. Doelling, X. Wu, X. Xiong)
  - NASA CALIPSO/CloudSat

- NOAA points-of-contact or collaborators, as applicable
  - K. Knapp, NCDC
  - X. Wu, NESDIS
- Target NOAA Data Center: NCDC
- How can the CDR Program Office help you?
  - Clear guidelines